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HYPOTHETICAL ZERO YAW DRAG TRAJECTORY OF SPINNING PROJECTILES BETWEEN M = 5 AND M = 10

William F. Donovan

November 1984

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US ARMY BALLISTIC RESEARCH LABORATORY
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18. SUPPLEMENTARY NOTES

The program tab for use with the Hewlett Packard 97 calculator is available on application to BRL.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Drag Coefficient
Retardation
Hypersonic Flow
Time of Flight

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) jmk

From a review of existing techniques and extrapolation of lower velocity data, the drag characteristics of a typical spin stabilized projectile are proposed for application in the range 5<M<10.

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I. INTRODUCTION

A previous report[1] proposed a drag determination procedure for hypervelocity "Kinetic Energy" projectiles intended for anti-tank application.

A similar estimating procedure for use in antiaircraft fire for spin stabilized projectiles is now offered. The basic boundary conditions are retained, i.e., sea level air density and flat trajectory, and it is assumed that the projectile geometry is reasonably conventional.

The calculation is quite similar to that of Reference 1, except that the fin contribution is not required. Also, retardation and time-of-flight print outs have now been included. The results are presented in desk-calculator form and the program is included as an Appendix.

II. PROCEDURE

Figure 1 is a schematic of a typical spin stabilized projectile and Figure 2 defines the nomenclature employed in the analysis. Standard sea level air properties are assumed.

A. A conventional partition of the drag coefficient as composed of wave, viscous and base components is assumed. The wave drag coefficient is taken as

$$C_{DW} = .7\ M^{-.28}\ \ell_n^{\ -1.73}$$

directly from Reference 2, which examined a large number of spin stabilized projectiles to the Mach 5 region and correlated the experimental data to develop estimating criteria. Figure 3 indicates the transposition.

The hypersonic base drag coefficient is found by inference from experimental data on cones. A patch procedure, as described in Appendix A, is imposed and the result is a bilinear characteristic from M=2 to M=10 with the knee at M=5. Available references offer little insight into the aerodynamics of hypersonic flow in the wake of cylindrical bodies. The wake flow behind cones has been investigated, however, and the results of these open literature studies is included in Appendix A. Thus,

$$C_{DB} = (.050 - .0034M)\ d_b^{\ 2}$$

is used for use in the range $5<M<10$.

---

1 *W.F. Donovan, "Hypothetical Zero Yaw Drag Coefficient of Kinetic Energy Projectiles Between M=5 and M=10," ARBRL-MR-03041, August 1980, ADA # 090009.*

2 *W.F. Donovan and Susan A. Wood, "Automatic Plotting Routines For Estimating Properties Of Spin Stabilized Projectiles In Flat Fire Trajectories At 2<M<5," ARBRL-MR-03204, October 1982, AD #120658.*

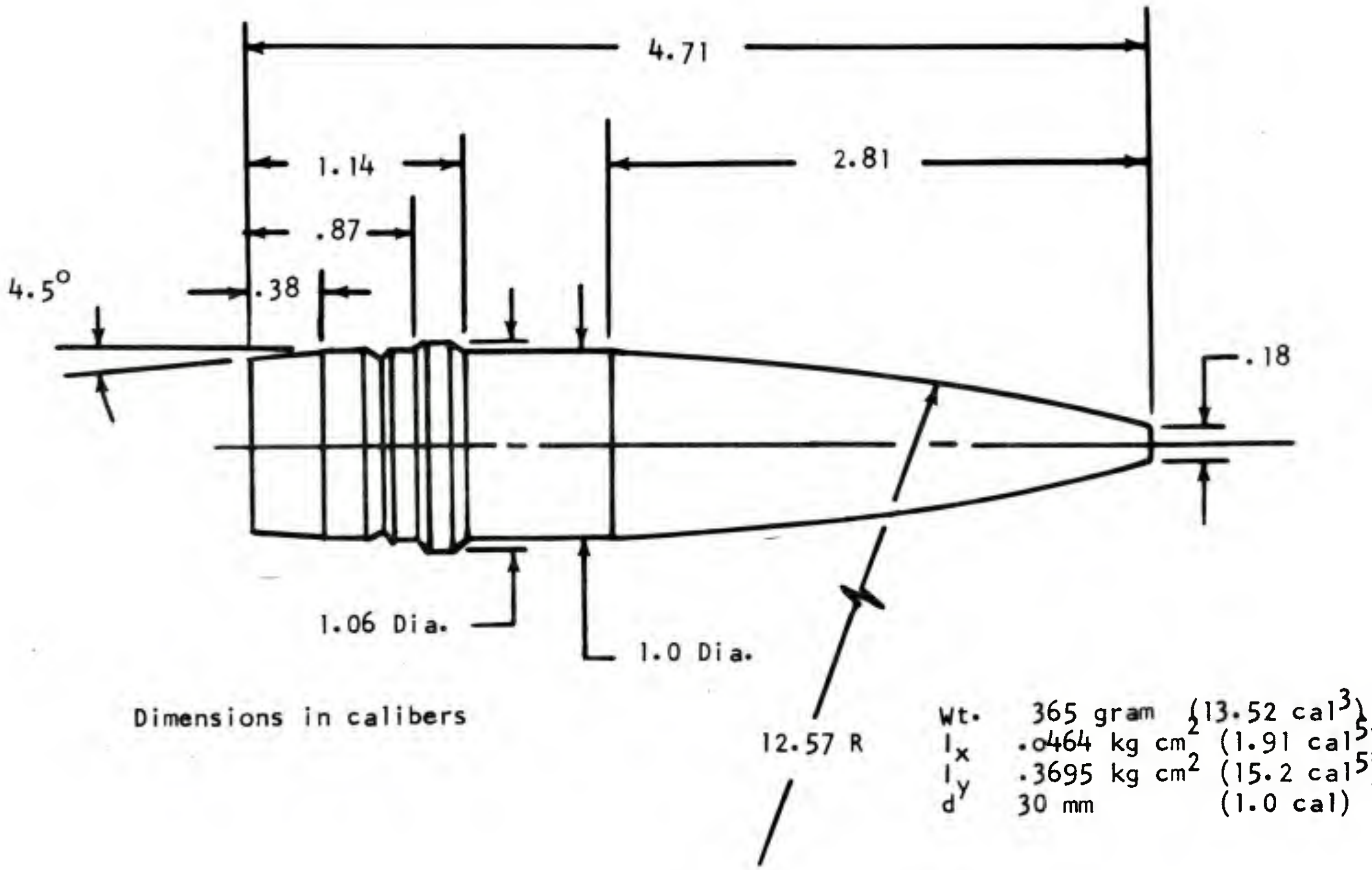

Figure 1. Typical Spin Stabilized Projectile

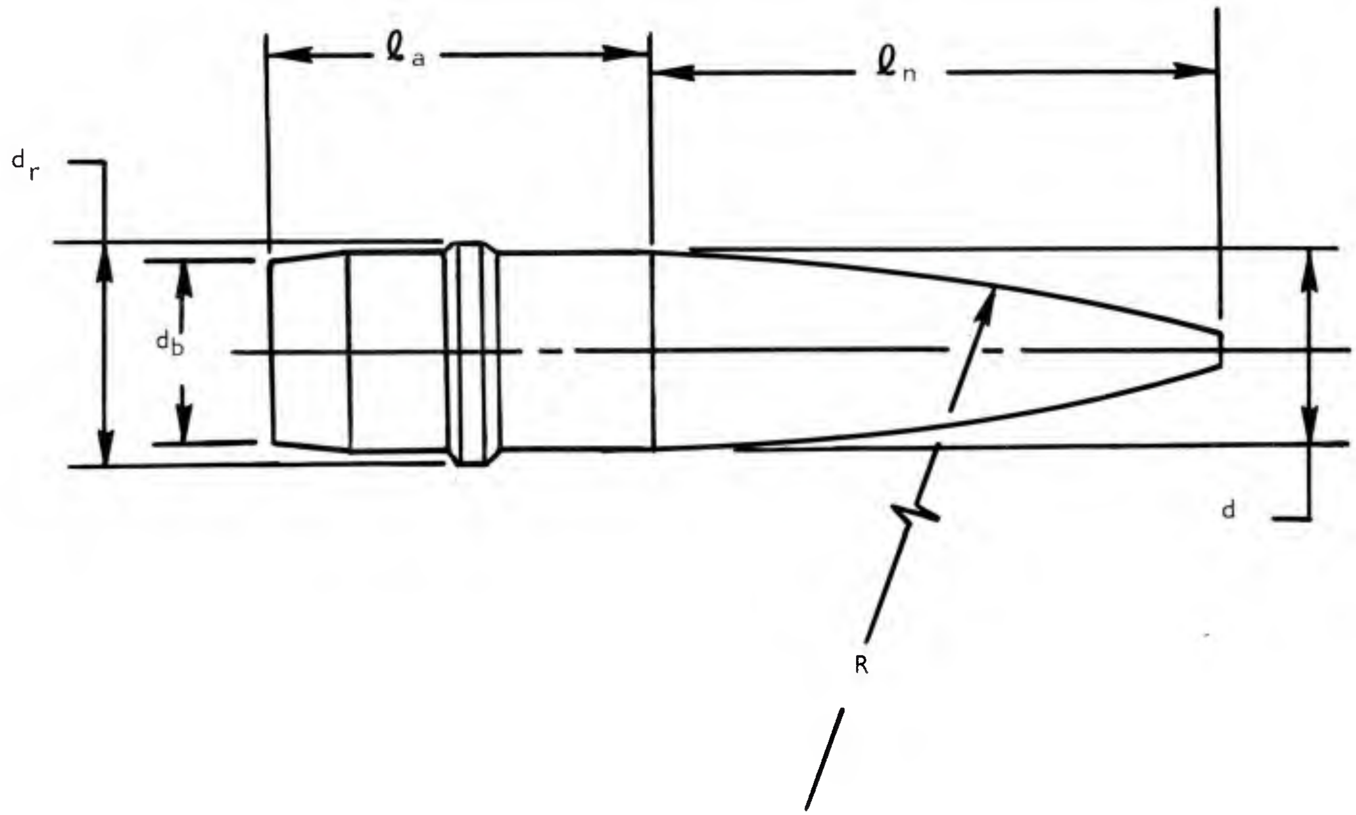

Figure 2. Projectile Nomenclature

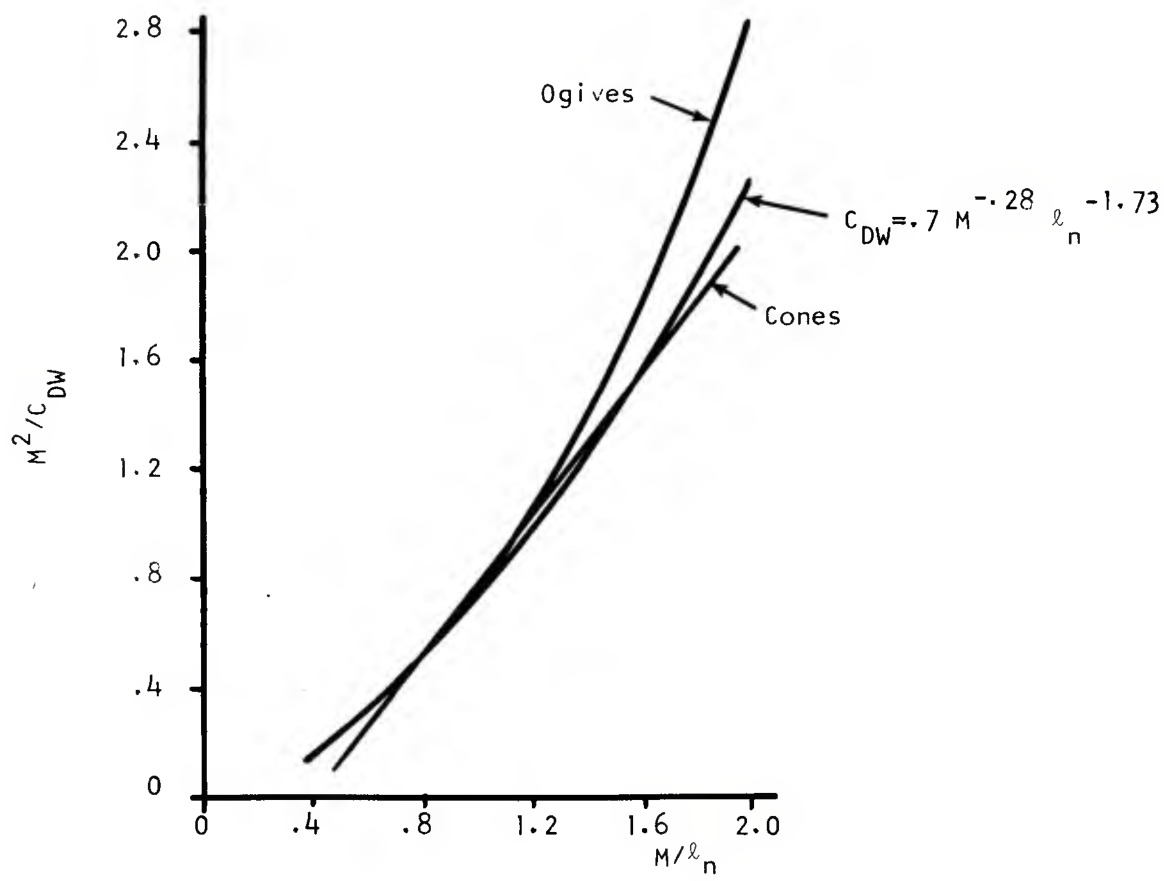

Figure 3. Nose Wave Drag Coefficient Correlation

The viscous drag component, C_{DV}, is obtained by Mach extrapolation, Figure 4, of the friction factor as employed in Reference 1 and of the effect of the ogive as empirically found in Reference 2.

$$C_{DV} = .000173\ (13.84 - 1.184M)\ (.083\ \ell_a + .0625\ \ell_n)\ (30)\ \text{EXP}^{(4.6/R)},$$

used for the range $5<M<10$. The viscous flow mechanics have been examined from divergent assumptions (Refer to Appendix B) and are considered here from the most conservative viewpoint.

For a projectile with a supercaliber rotating band, Reference 3 suggests a constant .015 C_{DR} in the lower velocity regions. This value can be expected to decrease in the hypervelocity regime and is taken here as

$$C_{DR} = .07143M\ d_r.$$

The total drag coefficient is then the sum of its parts, or

$$C_D = C_{DW} + C_{DB} + C_{DV} + C_{DR}.$$

B. The Mach number along the trajectory is given[4] as

$$M = \frac{b}{Je^{QS} - k},$$

where M = Mach number at range "s,"

J = Operational Parameter = $k + \dfrac{b}{M_0}$,

Q = Operational Parameter = $\rho\ \dfrac{Ab}{2m}$,

s = Range,

b = Intercept of C_D vs M characteristic,

k = Slope,

A_{ref} = Reference area, and

m = Mass of projectile.

---

3 *L.M. Freeman and R.H. Korkegi, "Projectile Aft-Body Drag Reduction by Combined Boat-Tailing and Base Blowing," AFAPI-TR-75-111, February 1976.*

4 *W.F. Donovan, "Simplified Determination of Retardation For Kinetic Energy Projectiles," BRL Memorandum Report No. ARBRL-MR-03020, May 1980, AD #086095.*

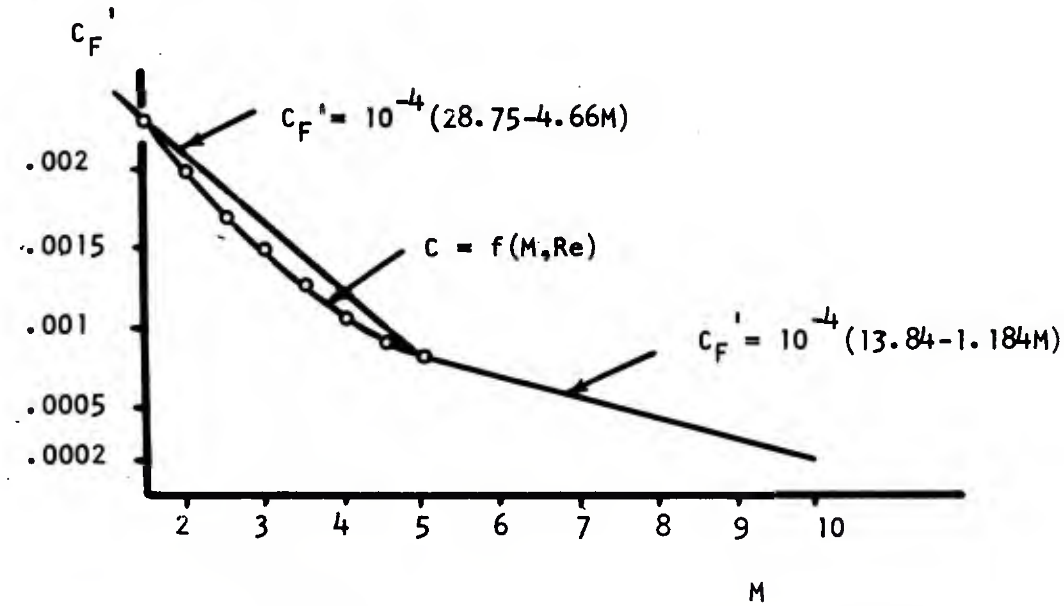

Figure 4. Conversion of Mach Number to C_F

C. The average velocity decrement over the selected range is determined by

$$\Delta V = \frac{(M_0 - M)}{s} \left(V_{sonic}\right),$$

where ΔV = the average velocity decrement over range "s" and V_{sonic} = ambient sonic velocity.

D. The time of flight is determined from the average velocity during the flight.

$$TOF = \frac{2\ s}{(M_0 + M)\ (V_{sonic})} \quad .$$

E. The input parameters required by the program are listed in Table 1. Entries to the HP-97 calculator storage are in caliber units where the reference diameter is either inches or millimeters. The selected range is given as meters. The projectile weight may be inserted as pounds, grams or cubic calibers. It is necessary to employ the secondary storage for recurring constant numbers. They are listed in Appendix C.

TABLE 1. INPUT PARAMETERS FOR PROGRAM OPERATION

HP-97 REGISTER	SYMBOL	IDENTIFICATION	UNITS
A			
B			
C			
D	dr	Rotating Band Diameter	Cal
E	s	Range	Meters
I	5	Lower Mach Limit	
0	M_0	Muzzle Mach Number	
1	ℓ_n	Length of Nose	Cal
2	ℓ_a	Length of Afterbody	Cal
3	d_b	Base Diameter	Cal
4	R	Ogive Radius	Cal
5	m	Mass of Projectile	Gram
6	m	Mass of Projectile	Pounds
7	m	Mass of Projectile	Cal^3
8	d	Diameter of Projectile	mm

III. RESULTS AND CONCLUSIONS

For the projectile described in Figure 1, the input parameters for Table 2 are determined and the calculator program prints out the results as shown in Table 3.

Since no range data is available for comparison, verification is lacking. However, within the regime where cone results are applicable, indications are that the procedure is reliable and usable for preliminary estimating. Where alternate formulations of the drag coefficients of the components (wave, viscous and base) can be established, their substitution into the program is quite simple. The subsequent operations are identical.

TABLE 2. INPUT PARAMETERS FOR HS-831 PROJECTILE

REGISTERS	SYMBOL	ENTRY VALUE	UNITS
A			
B			
C			
D	d_r	1.06	Cal
E	s	1500	Meters
I	M (initial)	5	
0	M_0	7	
1	ℓ_n	2.81	Cal
2	ℓ_a	1.90	Cal
3	d_b	.94	Cal
4	R	12.57	Cal
5	m	361.35	Grams
6			
7			
8	d	29.9	mm
9			

TABLE 3. SAMPLE PROGRAM OPERATION

Primary Registers

7.000000000	0
2.810000000	1
1.900000000	2
0.940000000	3
12.57000000	4
361.3580000	5
0.000000000	6
0.000000000	7
29.90000000	8
0.000000000	9
0.000000000	A
0.000000000	B
0.000000000	C
1.060000000	D
1560.000000	E
5.000000000	I

Secondary Registers

25.40000000	0
0.000204800	1
39.37000000	2
0.000017344	3
0.000000000	4
0.002392000	5
0.036111000	6
-0.003400000	7
0.053000000	8
0.000000000	9

Program Output

C_D	0.120662166	***
M	5.000000006	***
	0.110723975	***
	6.000000006	***
	0.102976366	***
	7.000000006	***
	0.096182885	***
	8.000000006	***
	0.090060041	***
	9.000000006	***
	0.084429932	***
	10.00000006	***
Range in calibers	50167.12376	***
Mach number at range	6.061760514	***
Retardation in Meters/sec/kilometer	213.9186028	***
Time of flight in sec	0.652494529	***

REFERENCES

1. W.F. Donovan, "Hypothetical Zero Yaw Drag Coefficient of Kinetic Energy Projectiles Between M=5 and M=10," ARBRL-MR-03041, August 1980, ADA # 090009.

2. W.F. Donovan and Susan A. Wood, "Automatic Plotting Routines For Estimating Properties Of Spin Stabilized Projectiles In Flat Fire Trajectories At 2<M<5," ARBRL-MR-03204, October 1982, AD #120658.

3. L.M. Freeman and R.H. Korkegi, "Projectile Aft-Body Drag Reduction By Combined Boat-Tailing and Base Blowing," AFAPI-TR-75-111, February 1976.

4. W.F. Donovan, "Simplified Determination of Retardation For Kinetic Energy Projectiles," BRL-MR-03020, May 1980, AD #086095.

B-1. W.C. Lyons, Jr. and H.S. Brown, "The Drag of Slightly Blunted Slender Cones," NOLTR 68-3, January 1968.

B-2. N.A. Zarin, "Base Pressure Measurements On Sharp and Blunt 9 Degree Cones At Mach Numbers From 3.50 to 9.20," BRL MR 1709, November 1965, AD# 369084.

B-3. Robert L. McCoy, "MC Drag - A Computer Program For Estimating The Drag Coefficients of Projectiles," ARBRL-TR-02293, February 1981, AD #A098110.

B-4. L.S. Stivers, Jr., "Calculated Pressure Distributions and Components of Total Drag Coefficients For 18 Constant Volume Slender Bodies of Revolution At Zero Incidence For Mach Numbers From 2.0 To 12.0 With Experimental Aerodynamic Characteristics For Three Of The Bodies," NASA TN D-6536, October 1971.

APPENDIX A

PATCH PROCEDURE FOR TRANSITION TO HYPERSONIC REGIME

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PATCH PROCEDURE FOR TRANSITION TO HYPERSONIC REGIME

The base drag coefficient for a square base projectile in the range $2<M<5$ is given by

$$C_{DB} = (.133 - .02\ M)$$

and acquires a value of .033 at M=5. For an assumed decrement to .016 at M=10,

$$.133 - .02\ M = - k\ M + b$$

or

$$.033 = b - 5\ k$$

with $.016 = b - 10\ k,$

$$k = .0034, \text{ and}$$

$$b = .05.$$

Thus ,

$$C_{DB} = .05 - .0034\ M.$$

The skin friction coefficient is similarly determined. At M = 10 the extrapolated decrement produces $C_{F'} = .0002$. This leads to

$$28.75 - 4.166\ M = z - w\ M,$$

where z and w complete the linearization in M.

Then ,

$$z = 13.84$$

with

$$w = 1.184$$

are suitable coefficients for the range $5<M<10$.

APPENDIX B

DISCUSSION OF BASE DRAG COEFFICIENT

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DISCUSSION OF BASE DRAG COEFFICIENT

Lyons and Brown[B-1] and Zarin[B-2] offer results of work on cones. The Lyons and Brown base drag coefficient assumes a perfect vacuum in the immediate wake of the body while the Zarin data are predicated on pressure measurements on the model mounted in a wind tunnel facility. McCoy[B-3] calculates base drag at lower Mach numbers for flight bodies on the basis of a Prandtl-Meyer expansion around a sharp corner. Extrapolation to the higher Mach numbers precisely duplicates the Lyons and Brown data. The results are compared with values from this report in Figure B-1.

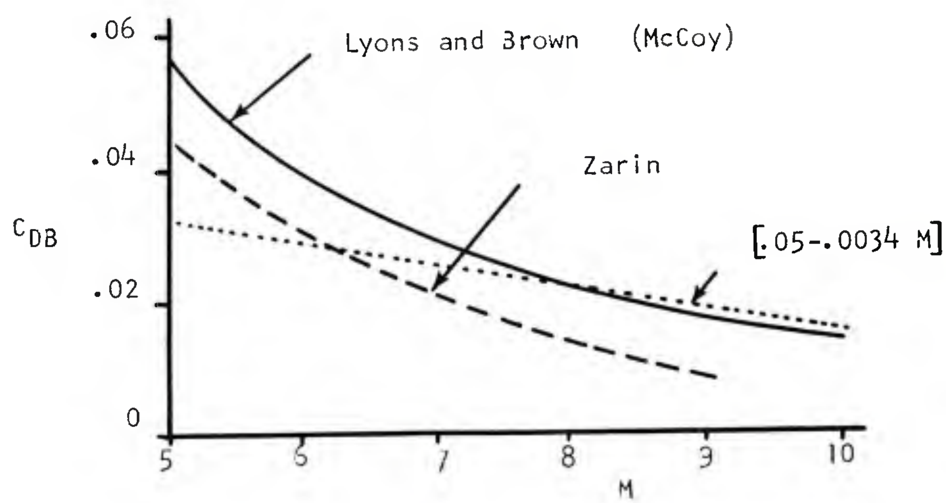

Figure B-1.

The linear assumption of the present report intercepts the Zarin data at M = 6 and coincides with the Lyons and Brown - McCoy analyses from M = 8 to M = 10. The viscous contribution to the drag is treated by Lyons and

B-1 *W.C. Lyons, Jr. and H.S. Brown, "The Drag of Slightly Blunted Slender Cones," NOLTR 68-3, January 1968.*

B-2 *N.A. Zarin, "Base Pressure Measurements On Sharp and Blunt 9 Degree Cones At Mach Numbers From 3.50 to 9.20," BRL MR 1709, November 1965, AD# 369084.*

B-3 *Robert L. McCoy, "MC Drag - A Computer Program For Estimating The Drag Coefficients of Projectiles," ARBRL-TR-02293, February 1981, AD# A098110.*

Brown as a boundary layer phenomena with additional components due to induced pressure and transverse curvature effects. Zarin considers the viscosity to be negligible in comparison with other terms. Stivers[B-4] offers a conventional treatment whereby the laminar regime is superseded by a transitional and turbulent flow, and then converts the body of revolution to equivalent flat plate configuration. This present report simply extrapolates from lower Mach number data to estimate the high-end base drag coefficient. The results show qualified agreement with the Lyons and Brown argument.

B-4 *L.S. Stivers, Jr., "Calculated Pressure Distributions and Components of Total Drag Coefficients For 18 Constant Volume Slender Bodies of Revolution At Zero Incidence For Mach Numbers From 2.0 To 12.0 With Experimental Aerodynamic Characteristics For Three Of The Bodies," NASA TN D-6536, October 1971.*

APPENDIX C

PROGRAM LISTING

```
001  *LBLB   21 12
002   RCL8   36 08
003   X>0?   16-44
004   GSB1   23 01
005   GSB2   23 02
006  *LBL1   21 01
007   RCL8   36 08
008    P⇄S   16-51
009   RCL0   36 00
010    P⇄S   16-51
011      ÷     -24
012   STO9   35 09
013  *LBL2   21 02
014   RCLD   36 14
015   STO8   35 08
016   RCL5   36 05
017   X>0?   16-44
018   GTO3   22 03
019   GTO6   22 06
020  *LBL3   21 03
021   RCL5   36 05
022      4      04
023      5      05
024      4      04
025      ÷     -24
026   STO6   35 06
027  *LBL6   21 06
028   RCL1   36 01
029   STO5   35 05
030   RCLE   36 15
031    P⇄S   16-51
032   STO4   35 04
033   RCL2   36 02
034    P⇄S   16-51
035   STO4   35 04
036      ×     -35
037   RCL9   36 09
038      ÷     -24
039   STOE   35 15
040  *LBL8   21 08
041   RCL7   36 07
042   X>0?   16-44
043   GSB9   23 09
044   GSBE   23 15
045  *LBL9   21 09
046   RCL9   36 09
047   ENT↑     -21
048      3      03
049     Yˣ      31
050   RCL7   36 07
051      ×     -35
052    P⇄S   16-51
053   RCL6   36 06
054    P⇄S   16-51
055      ×     -35
056   STO6   35 06
057  *LBLE   21 15
058   RCLI   36 46
059    P⇄S   16-51
060   RCL7   36 07
061    P⇄S   16-51
062      ×     -35
063      .     -62
064      0      00
065      5      05
066      +     -55
067   RCL3   36 03
068     X²      53
069      ×     -35
070   STOA   35 11
071   RCL2   36 02
072    P⇄S   16-51
073   RCL8   36 08
074    P⇄S   16-51
075      ×     -35
076   STO9   35 09
077   RCL5   36 05
078      1      01
079      6      06
080      ÷     -24
081   RCL9   36 09
082      +     -55
083   STO9   35 09
084      3      03
085      0      00
086   ENT↑     -21
087      4      04
088      .     -62
089      6      06
090   RCL4   36 04
091      ÷     -24
092     Yˣ      31
093   RCL9   36 09
094      ×     -35
095   STOC   35 13
096    P⇄S   16-51
097   RCL1   36 01
098   RCLI   36 46
099      ×     -35
100   RCL5   36 05
```

```
101     +       -55
102    P⇄S    16-51
103    RCLC   36 13
104     ×       -35
105    STOC   35 13
106     .       -62
107     7        07
108    RCLI   36 46
109    ENT↑     -21
110     .       -62
111     2        02
112     8        08
113    Y^X       31
114     ÷       -24
115    RCL5   36 05
116    ENT↑     -21
117     1        01
118     .       -62
119     7        07
120     3        03
121    Y^X       31
122     ÷       -24
123    STO9   35 09
124    RCLI   36 46
125     1        01
126     4        04
127     ×       -35
128    1/X       52
129    RCL8   36 08
130     ×       -35
131    RCL9   36 09
132     +       -55
133    RCLA   36 11
134     +       -55
135    RCLC   36 13
136     +       -55
137    PRTX     -14
138    STO1   35 01
139    RCLI   36 46
140    PRTX     -14
141    SPC    16-11
142     5        05
143    X=Y?   16-33
144    GTOB   22 12
145    GTOC   22 13
146   *LBLB   21 12
147    RCL1   36 01
148    STO2   35 02
149   *LBLC   21 13
150    ISZI 16 26 46
151    RCLI   36 46
152     1        01
153     1        01
154    X>Y?   16-34
155    GTOE   22 15
156    GTOD   22 14
157   *LBLD   21 14
158    RCL1   36 01
159    STO3   35 03
160    RCL2   36 02
161     -       -45
162    CHS      -22
163     5        05
164     ÷       -24
165    STO1   35 01
166     5        05
167     ×       -35
168    RCL2   36 02
169     -       -45
170    CHS      -22
171    STO2   35 02
172    RCL6   36 06
173     ÷       -24
174    P⇄S    16-51
175    RCL3   36 03
176    P⇄S    16-51
177     ×       -35
178    RCLE   36 15
179    PRTX     -14
180     ×       -35
181    e^X       33
182    STO9   35 09
183    RCL2   36 02
184    RCL0   36 00
185     ÷       -24
186    RCL1   36 01
187     +       -55
188    RCL9   36 09
189     ×       -35
190    RCL1   36 01
191     -       -45
192    RCL2   36 02
193     ÷       -24
194    1/X       52
195    PRTX     -14
196    STOA   35 11
197    RCL0   36 00
198     -       -45
199    CHS      -22
200    P⇄S    16-51
```

```
201    RCL4    36 04
202      ÷       -24
203     P⇄S    16-51
204      3        03
205      4        04
206      2        02
207      0        00
208      0        00
209      0        00
210      ×       -35
211    PRTX      -14
212    RCLA    36 11
213    RCL0    36 00
214      +       -55
215      1        01
216      7        07
217      6        06
218      ×       -35
219     P⇄S    16-51
220    RCL4    36 04
221      ÷       -24
222     1/X       52
223    PRTX      -14
224     R/S       51
```

LIST OF SYMBOLS

A	Area of cross section of projectiles
A_{ref}	Reference area (.785 cal^2)
C_D	Total drag coefficient
	$= \frac{2D}{\rho V^2 A_{ref}}$
C_{DB}	Base drag coefficient
C_{DR}	Rotating band drag coefficient
C_{DV}	Viscous drag coefficient
C_{DW}	Wave drag coefficient
$C_{F'}$	Skin friction factor for flat plate viscous flow
$C_{F''}$	Empirical constant
$C_{P'''}$	Conversion factor between flat plate and cylindrical viscous flow
D	Drag force
J	Operational parameter
	$= k + \frac{b}{M_0}$
M	Mach number
M_0	Muzzle Mach number
Q	Operation parameter
	$= \frac{Ab}{2m}$
R	Radius of nose ogive
R_e	Reynolds number
TOF	Time of flight of projectile
b	Intercept of C_D-M characteristic
d	Representative diameter

LIST OF SYMBOLS (Continued)

d_b	Base diameter
d_r	Rotating band diameter
k	Slope of C_D-M characteristic
ℓ_a	Length of afterbody of projectile
ℓ_n	Length of nose of projectile
m	Mass of projectile
v	Velocity of projectile
V_{sonic}	Sonic velocity at ambient conditions
ΔV	Velocity decrement of projectile
ρ	Ambient air density

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